UNITED STATES DEPARTMENT OF LABOR
Mine Safety and Health Administration

EVALUATION OF THE DYNO-NOBEL HOTSHOT ELECTRONIC BLAST INITIATION SYSTEM--- REQUIREMENTS FOR SHUNTING AND CIRCUIT TESTING

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By

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Purpose

MSHA has received inquiries about how its requirements for shunting and circuit testing are applied to electronic detonators for use in mine blast initiation systems. The purpose of this specific report is to discuss the technical and field evaluation and the issues of “shunting” and “circuit testing” for the Dyno-Nobel HotShot electronic detonator initiation system for blasting with regard to meeting the intended MSHA standards.

Introduction

With respect to **electric** detonators, the coal and metal-nonmetal mine requirements for shunting and circuit testing are specified in 30 CFR 77.1303 (y)(1),(2),(3) and 77.1303(z); 56.6401(a),(b),(c); 56.6407(a),(b),(c),(d) and 57.6401 (a),(b),(c) and 57.6407 (a) and 57.6407 (b). **Electric** blasting systems are designed differently than electronic detonator initiation systems and the design features are not the same. Each electronic detonator initiation system differs in design, construction, operation and testing features. To resolve the issue of “shunting and “circuit testing”, technical information was evaluated and a mine site examination was made on the Dyno-Nobel HotShot electronic detonator system.

This report presents the findings of an evaluation of the Dyno-Nobel HotShot electronic blast initiation system regarding the shunting and circuit testing requirements as required by Mine Safety and Health Administration (MSHA) regulations for electrically initiated detonators. The HotShot electronic blast initiation system consists of the HotShot electronic detonator with connecting wires, the HotShot Tagger circuit testing and programming device, the HotShot blast cradle, and the HotShot blast key. An evaluation of the Dyno-Nobel HotShot electronic detonation system was necessary to determine its intrinsic shunting and circuit testing capabilities. To ensure the design of this electronic detonation system meeting or exceeding intended MSHA safety standards, both a technical review and an examination of use in the field were performed on the HotShot system. The design and operational aspects of the HotShot system were reviewed and evaluated from technical information supplied from Dyno Nobel. Subsequently, a field visit was made to examine and witness the use of the HotShot electronic blast initiation system at a surface mine site in Richmond, Virginia.

Electric Detonators

Electric detonator systems for performing blasting operations have been in use in the mining industry for many decades. They are used in both series and parallel blasting circuits. An electric detonator consists of two leg wires embedded in a metal shell which contains a high explosive base charge designed to initiate other explosives. Electric detonators are typically designed with an ignition mixture, a pyrotechnic fuse train (for the delay element) and a base charge, respectively (See Figure 1). A thin metal filament, known as a bridgewire, is attached between each end of the leg wire and is embedded in an ignition mixture. The pyrotechnic delay element is designed to burn at an approximated rate. The length and composition of the pyrotechnic train control the approximate rate of burn and thus the timing of when the detonator fires. Electric detonators are supplied with a distinctive, numbered tag to facilitate easy identification of the delay period. Since the approximate rate of burn is subject to variation, the firing time accuracy of the electric detonator is affected. When sufficient electrical current passes through the bridge wire, it becomes hot enough to ignite the ignition mixture. This event initiates the pyrotechnic element in the delay train which then initiates the base charge.

All electric detonators produced in the USA have shunts on the free ends of the leg wires. The shunt provides a low resistance path to prevent current from flowing through the bridge wire of the electric detonator. With a shunt, both of the leg wires are at the same potential to prevent extraneous current flow into the detonator. In addition, some designs completely enclose the ends of the wires in order to prevent corrosion and to prevent bare wires from contacting extraneous electrical current sources. The shunt is removed when an electric detonator is connected into the blasting circuit.

Electric detonators are designed to fire when a certain level of electrical energy is supplied. If electrical energy is applied too early or applied at too low of a level, the likely result is premature detonation or a failed detonation which is also known as a misfire. An extraneous source of electric current represents a potential source for initiation of an electric detonator. Sources such as lightning, high voltage power lines, radio transmitters, and static electricity must be avoided when preparing a blast site. There are also occurrences where the energy from lightning has traveled several miles along pipes or cables into an underground mine and can represent an unsuspected source for initiation of electric detonators.

When electric detonators are initiated, current leakage from the blasting circuit must also be prevented. If bare wires are allowed to come into contact with another conductor or even a conductive portion of the ground, some of the electric energy may leak out of the circuit causing misfires. Other events that affect the amount of current reaching electric detonators occur when either too many electric detonators are connected into the circuit and the increased resistance causes a greater voltage drop than intended or if there is a failure to connect all the intended electric detonators into the circuit.

When using electric detonators, the continuity and resistance of the individual detonator as well as the entire circuit needs to be tested with a blasting galvanometer. A blasting galvanometer is used to check the individual detonators prior to making the primer and again prior to stemming the borehole. Care should be taken when stemming a borehole to prevent any possible damage to the detonator leg wires. Once the circuit is completely wired, it should be checked again. When the blast line is connected to the circuit, the resistance needs to be checked prior to connecting the blasting unit.

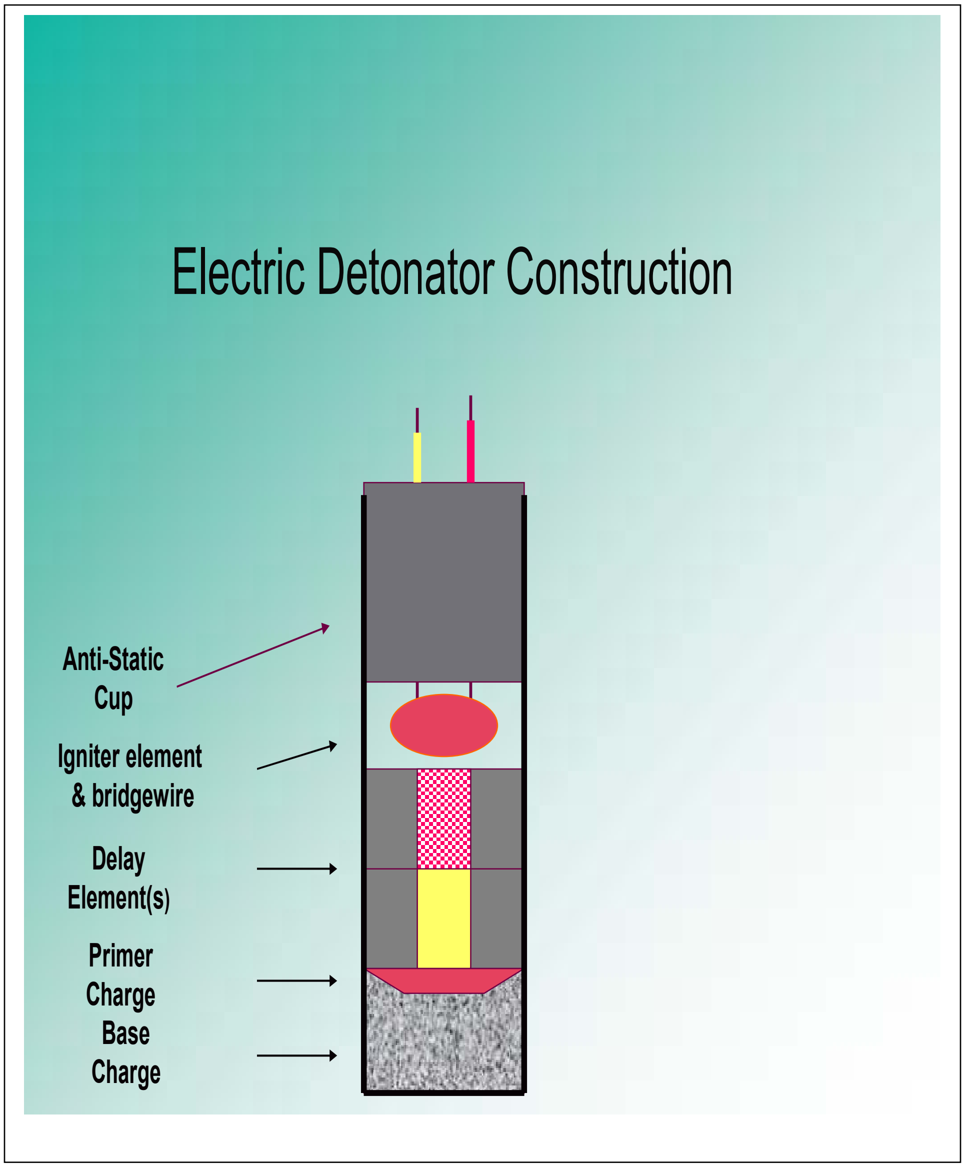

Figure 1 - Electric detonator design (generic)

<u>Electronic Detonators</u>

Electronic detonator systems are new technology advancements for the initiation of blasts in mining operations. Their introduction for use in mine blasting operations continues to advance. Several advantages for using electronic detonators are precise timing, reduced vibrations, a reduced sensitivity to stray electrical currents and radio frequencies, and a great reduction in misfires through more precise circuit testing.

Electronic detonators have been designed to eliminate the pyrotechnic fuse train that is a component of electric detonators, thus improving timing accuracy and safety. For the electronic detonators, typically an integrated circuit and a capacitor system internal to each detonator separate the leg wires from the base charge. Depending on the design features of the electronic detonator, the safety and timing accuracy can be greatly improved. An example of the constructional features of an electronic detonator is shown in Figure 2. The electronic detonator is obviously a more complex design compared to a conventional electric detonator. A specially designed blast controller unique to each manufactured system transmits a selectable digital signal to each wired electronic detonator. The signal is identified by each electronic detonator and the detonation firing sequence is accurately assigned. The manufacturer's control unit will show any incomplete circuits during hookup prior to initiation of the explosive round. The wired round won't fire until all detonators in the circuit are properly accounted for with respect to the current blasting plan layout.

Using electronic detonators, as designed and recommended by the manfacturer, requires specialized devices to identify, program and arm the blasting circuit. The detonators, connecting wires and accompanying items such as taggers, loggers, circuit testers and blast controllers are typically referred to as electronic blasting systems or electronic initiation systems.

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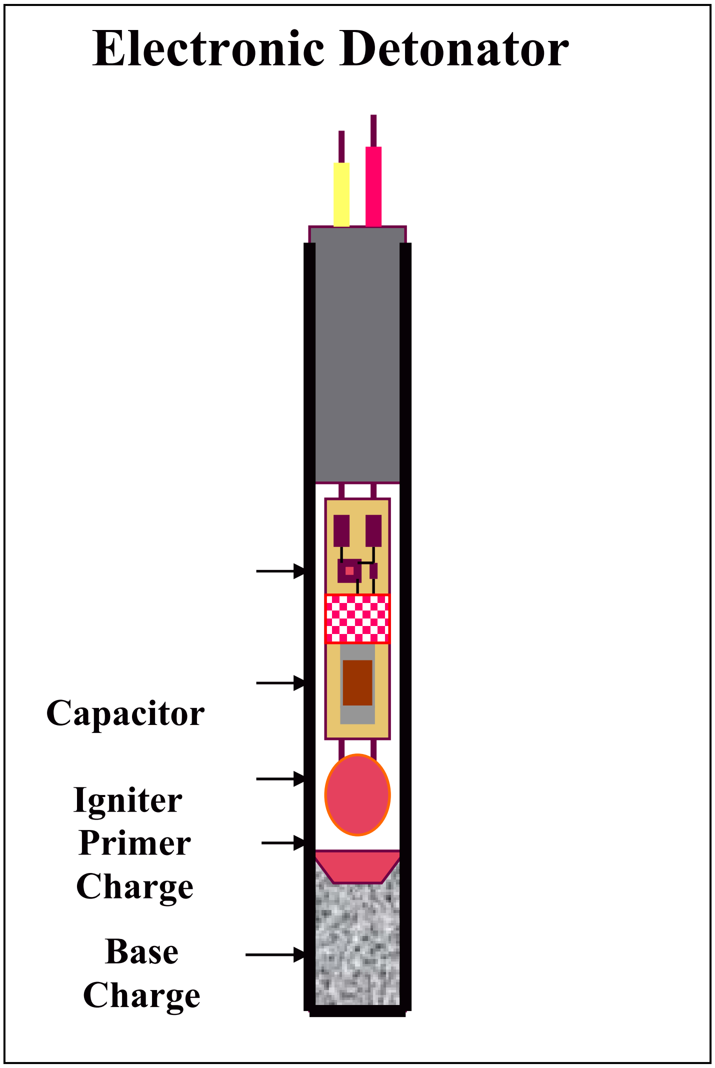

Figure 2 - Electronic detonator design (generic)

Technical Discussion

As part of the resolution of the “shunting” and “circuit testing” issues, MSHA conducted a technical evaluation of the HotShot electronic blast initiation system which includes the HotShot electronic detonator with connecting wires; the HotShot Tagger, a circuit testing and programming device, the HotShot blast cradle, and the HotShot blast key. The HotShot electronic detonator is packaged with the identification tag and bar code on the exterior wrapper (Figure 3). It is shipped in a protective card board sheath contained in a spool of connecting wire (Figure 4). The assigned unique identification number is held on the internal chip.

Figure 3 - The HotShot electronic detonator with identification tag on spool

Figure 4 - HotShot electronic detonator, cardboard sheath and connecting wire

In preparing a round to be blasted, the HotShot electronic detonator is inserted into a booster to form a primer to be positioned in a blast hole powder column Once the primers are positioned and the powder charge added, the condition of each detonator is tested using the HotShot Tagger at the borehole before the hole is stemmed. The detonator wire is plugged into the receptacle on the Tagger, as shown in Figure 5 and the detonator circuitry is tested for short circuits, open circuits, and operational integrity. Once these tests have been made, the connection plug is removed from the Tagger and the steps are repeated for each electronic detonator in the blast hole powder column before stemming.

Figure 5 - HotShot Tagger showing plug connection to detonator wire

After an electronic detonator has been checked, it is plugged into the other electronic detonators in the row using the HotShot connection system illustrated in Figure 6. The entire row is then checked to verify all electronic detonators are properly connected and ready for programming. If an electronic detonator has become unplugged or a wire broken, the Tagger indicates the last electronic detonator detected informing the blaster which electronic detonator has a break in the circuit. After each row is set and tested, the entire network is then tested for opens and shorts. The Tagger is able to provide a top view of the blasting pattern indicating how many electronic detonators are detected in each blast hole. This information is then checked against the blasting plan.

Once the shot plan has been electronically verified and compared with the written blasting plan, the entire network is connected to a bench controller shown in Figure 7. The bench controller provides the interface between the detonators in the network and the blast controller. The blasting network is connected with four-wire leads but the blast controller communicates with the network via a two-wire lead in. The interface with the bench controller is shown in Figure 8. The Tagger then checks again for firing line continuity, extra detonators, and for detonators that have faulty connections or no connections at all. The functionality check using the HotShot Tagger serves as a circuit continuity check for meeting the MSHA requirement. The information is then checked against the blast plan. The Tagger is then connected to the HotShot Blast Cradle to become the blasting machine. The Tagger in the blasting machine again verifies the system hardware, software and the integrity of the wired round. This information is displayed on the blasting machine screen before the blast can be armed and fired. The Tagger as a blasting machine will not arm the round until the system operational check is completed and no errors are indicated. The blast site must be cleared prior to arming the round. The round is armed by connecting the lead-in wire to the blasting machine. Then the blaster can fire the round it transmits a digital signal to each wired electronic detonator. The signal is identified by each electronic detonator and the detonation firing sequence is accurately assigned. The manufacturer's control unit will show any incomplete circuits during hookup prior to initiation of the explosive round. The wired round won't fire until all detonators in the circuit are properly accounted for according to the blasting plan layout. Figure 9 is an illustration of the HotShot Tagger in the HotShot Blast Cradle to form the blasting machine.

Figure 6 - HotShot connecting plugs with each spool

Figure 7 - Bench controller connects all rows and branches on bench

Mine Field Trip

A field trip was made to observe the use of the HotShot electronic detonator system at a surface quarry mine located in Richmond, Virginia. At the blast site, an examination was made of the use of the HotShot electronic detonator system including electronic detonators, connection devices used between blast holes, row and bench controllers, as well as the Tagger, Blast Cradle and Blast Key. The system performed as specified for its use in the field. The system detected open blasting circuits which enabled the blasting crew to specifically locate and correct the fault while setting up the blasting network. The operational features of the system served to prevent mistakes that can lead to safety problems such as misfires. The blast pattern consisted of 27 holes six and a half inches in diameter. Blast hole depth ranged from 50 to 53 feet. The electronic detonators and boosters were laid out near the collar of each blast hole and assembled. The primers were lowered into each blast hole prior to loading with an ammonium nitrate and fuel oil emulsion. The emulsion was pumped into each blast hole from a Unibody bulk loading truck pictured in Figure 10.

The shot design required a small deck at the top of the column that was separated from the larger deck with four and a half feet of stemming. After stemming the lower deck, a sack charge weighing no more than eight pounds including primers was prepared as shown in Figures 11 and 12.

Figure 8 - Two-wire lead interfaces with four-wire lead at bench controller

Figure 9 - HotShot Tagger inserted in Blast Cradle with Blaster's Key

Figure 10 - Unibody emulsion truck

Figure 11 - Preparing upper deck charge at emulsion truck

Figure 12 - Inserting top deck charge into blast hole

In setting up the blast initiation system, the wires for each HotShot detonator were plugged into the base of the HotShot Tagger to test for circuit continuity and integrity. Then each row of detonators was checked from the end of the row at the HotShot row controller where the Tagger was able to communicate with each detonator and identify its location. Each detonator has a unique number assigned to it at the factory and when queried it responds to the Tagger with its identification code. The blast holes were then stemmed for the lower deck. This procedure was repeated for the upper deck.

Prior to stemming the upper deck, the detonator rows were tested. A problem emerged when the Tagger could not detect a second detonator in the top deck of each blast hole. The version of Tagger software being used that day would not allow only three detonators to be used in a single blast hole. The Tagger generated an error signal and prevented the blaster from proceeding with the setup procedure. This event provided further verification that the Tagger could assess the condition of the circuitry in the blast column and report it accurately to the blaster. Once an additional detonator was wired to each blast hole upper deck, the Tagger verified the location of each detonator and indicated the circuits for each row and for the entire shot were as required. The blaster then used the Tagger to program the timing delays for each detonator in each column per the blast plan. A top view of the blast plan is provided on the viewing screen and the blaster can compare the shot sequencing as reported with the written blasting plan as shown in Figure 13.

Figure 13 - Tagger report compared to written blasting plan

After verifying the shot was properly set, a two-wire lead was run from the bench controller to the blast initiation area two hundred yards away. The Tagger was inserted into the Blast Cradle and the blaster's personal HotShot Blast Key was also inserted into the Blast Cradle. The blaster entered his unique factory assigned identification number into the Blast Key to activate the Blast Cradle. The blaster performed another diagnostic on the entire blasting network and verified the shot area was properly cleared of personnel and equipment before radioing for the blast warning sirens to sound. After the third and final siren, the Blast Cradle was commanded to arm the detonators. Thirty seconds passed for the electronic arming procedure to complete and then the blast was initiated. All holes fired and there was little vibration, noise, and dust from the blast. The muck pile of blasted material is shown in Figure 14.

Figure 14 - Muck pile of blasted material

Conclusions

The HotShot electronic detonator is provided with an internal means of shunting that is at least as effective as the external shunting required for conventional electric detonators.

The HotShot electronic blast initiation system using the dedicated HotShot Tagger has its own integral testing and verification procedures that meet the intended MSHA requirements for circuit testing. Therefore, the HotShot electronic blast initiation system does not need to be physically shunted and circuit tested by using a blaster's galvanometer as would be performed for conventional electric detonators. Because of the unique design and construction of this system, it must be used according to the manufacturer's instructions.

Summary

Electronic detonator systems are one of the newer technologies being introduced into the mining industry. Their advantage is thorough pre-blast circuit testing and very precise detonator firing time.

The design and operational features of the HotShot electronic blast initiation system have been technically reviewed and the field use of the system has been observed a a surface mine site. The HotShot electronic blast initiation system has its own proprietary electronic design for shunting and circuit testing that meets the intended MSHA requirements. This system provides thorough pre-blast circuit testing and precise detonator firing times.. The HotShot electronic detonator safety features are obtained by the use of integrated circuit chips, internal capacitors, and other proprietary electronic features. The HotShot electronic blast initiation system cannot be initiated by a conventional blasting unit, nor can it be activated without entering security codes. However, electronic detonators can still be initiated by lightning, fire, and impact of sufficient strength. Their added safety features do not preclude proper transportation, storage and handling as an explosive product.

This report is posted on MSHA's web site and may be accessed under Technical Reports at http://www.msha.gov/TECHSUPP/ACC/ACCHOME.HTM. Also an MSHA Program Information Bulletin (PIB 04-20) on electronic detonators and requirements regarding shunting and circuit testing is available on MSHA's web site. The bulletin may be accessed at http://www.msha.gov/regs/complian/PIB/2004/pib04-20.htm.